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Development of a sector-specific and chemically-speciated VOCs emissions in Northeast Asia using the GAINS-IV framework

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Abstract

This study aims to develop a comprehensive VOC emission data which are readily to use in the policy planning and evaluation of mitigation measures in Northeast Asia and can be utilized in support of air quality modeling. In the present GAINS-Asia, most of VOCs emissions in Solvent sector which is account for more than 50% of total emission of VOC are classified 1 sector named “other VOCs”. I analyzed multiple emissions inventories to develop sector-specific VOCs emissions. In addition, the speciation profiles from were linked with the by-sector VOCs emissions to estimated speciated VOC emissions. These emissions were used in the air quality model to forecast and evaluate emission reduction policy over the East Asia atmosphere.

In order to improve the predictability of air pollution and climate change, it is essential to establish an emissions information not only for anthropogenic sources, but for natural ones. Since the Biogenic VOCs(BVOCs) emissions are another major contributor for the SOA formation, BVOCs also were estimated along with GAINS-based anthropogenic VOCs(AVOCs).

Through this study, 1)detailed sector-specific AVOCs emissions were developed in the GAINS model, 2)chemically-speciated AVOCs emissions were estimated in relation with the sector-based emissions inventory, 3)BVOC emissions were estimated using the MEGAN Model(Guenther et al., 2006) model, 4)The result was compared with PM2.5 emissions and SOA emissions for better understanding of the effect of VOCs reduction policies in Northeast Asia region.

As a result of SOAs emissions along with primary PM2.5 emissions were compared by sector and by country, SOAs emissions from solvents use sector are high due to its high SOA yield. The emission of SOA are higher than the emissions in primary PM2.5 for all three countries. From the scenario study, China shows high control potential in both primary PM and SOAs. Only SOAs emission, however, show a great control potential in Korea and Japan, where primary PM emissions are already been reduced much.

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Development of a sector-specific and chemically-speciated VOCs emissions in Northeast Asia using the GAINS-IV framework

1. Introduction

Fine Particulate Matter (Fine PM) in the atmosphere causes health impact to the human body, causes climate change, or causes visibility problems. Therefore, Northeast Asian countries such as Korea, China and Japan have been doing huge efforts to reduce fine particle. Fine particles can be classified according to the sources. There are Primary PM, which is directly emitted into the atmosphere, and Secondary PM, which is gaseous precursors converted into particles in the atmosphere. In KORUS-AQ, a large-scale observation campaign was conducted by NASA and the Korean Ministry of Environment in 2016, it was found that the pollution contribution of secondary PMs over Seoul Metropolitan area was more than 85%(NASA-NIER, 2017). Secondary Aerosol is sub-divided into Organic and Inorganic. And among them, Secondary Inorganic Aerosol (SIA) has the largest distribution. SIA's precursors and atmospheric transformations are relatively well known. However, Secondary Organic Aerosols(SOAs), which is caused by volatile organic compounds (VOCs), has a variety of emission sources and a complicated transformations process in the atmosphere, so its formation and reduction effects are not well known. In particular, VOCs are chemical compounds, and the composition of chemical species are different from the emission source. Therefore, SOA forming potential to secondary PM is different. So, it is necessary to be planned by evaluating with detailed sector-based emission data.

In this study, 1) the detailed sector-based VOC emission in Solvent sector was estimated for Korea, China and Japan in the GAINS system. And by applying the chemical speciation profile, I tried to understand the VOC emissions by chemical species. 2) In addition, the effectiveness of the VOC reduction policy was evaluated to improve fine PM.

2. Methodology

We mainly focused on the anthropogenic sources which the policy is applied. The VOC emissions was estimated by detailed sector in the GAINS4 system, and chemical speciated emission estimated.

The VOC policy effect analysis process for anthropogenic sources is divided into five steps. 1) VOC emissions were detailed by sector. So the activity level was updated for the detail sector, and a sector-specific VOC emission was estimated by GAINS-Global. 2) Chemical speciation profile was improvement by each sector. 3) So, VOC emissions was chemically speciated each sector by the Chemical Speciation Profile. 4) It was estimated how much it has SOA forming potential by each sector using chemically speciated VOC emission. 5) The primary pollutant and the secondary pollutant were compared and analyzed.

Also, for biogenic sources, BVOC emissions were estimated using the MEGAN model, and SOA emission was estimated with the SOA forming potential on the biogenic sources.

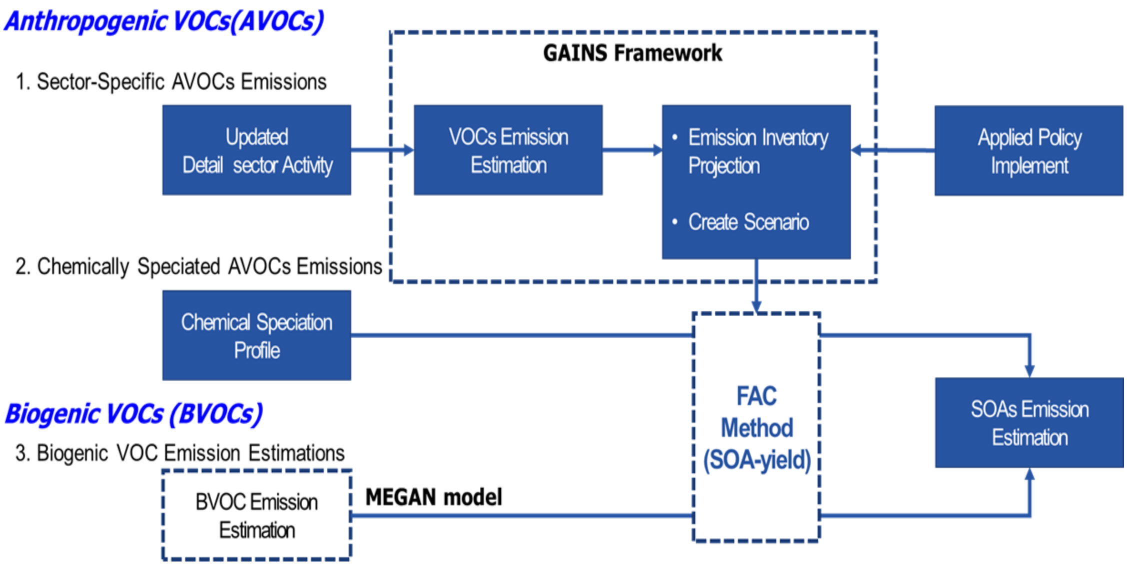


Figure 1 Research Flow

3. Result

3.1 Sector-specific AVOC emissions

VOC emissions were speciated by sector. The VOC sector can be subdivided into more than 40 in the GAINS system, most of the sectors are included in the Solvent. In Europe, the emission of the solvent sector in VOC is estimated in more than 20 sub-sectors, but in Asia, it is estimated only one sector named 'other VOC'. Detailed sectoral emission information is essential to implement and evaluate the regulations. We collected the national and regional statistics data and implemented it into GAINS model. As a result, VOC emissions were estimated for each sector, into 22 solvent sectors for China, 20 for Korea, and 17 for Japan.

The total emissions of VOCs for China were estimated to be 20.5 Tg/yr in 2015, the emissions in the solvents sector were estimated to be 11.7 Tg/yr, contributing 57% of the total anthropogenic emissions. In the domestic sector, the emissions were estimated to be 3.1 Tg/yr, contributing 15%, and the emissions in the road transport sector were estimated to be 1.5 Tg/yr, contributing 7%. In the solvent sector, VOC emissions from industrial paint use account for about 40% of the total solvents sector, followed by glue use, domestic solvents use, and wood preservation. The emission inventory in this work is 3% higher than in the ECLIPSE scenario of the GAINS and 24% higher than in the MEIC (Tsinghua Univ.).

The total emissions of VOCs for Korea were estimated to be 822 Gg/yr in 2015, the emissions in the solvents sector were estimated to be 490 Gg/yr, contributing 67% of the total anthropogenic emissions. In the solvent sector, emissions from industrial paint use account for about 23% of the total solvents sector, followed by glue use, domestic solvents use, and polystyrene process. The emission inventory in this work is 4% higher than in the ECLIPSE scenario of the GAINS and 11% higher than in the CAPSS (NIER).

For Japan, the total emissions of VOCs were estimated to be 1084 Gg/yr in 2015. The emissions in the solvents sector were estimated to be 704 Gg/yr, contributing 65% of the total anthropogenic emissions. The road transport sector emissions at 130 Gg/yr, contributing 12%, and the industrial process sector emission at 86 Gg/yr, contributing 8% of the total emissions. In Japan, VOC emissions from industrial paint use and vehicle manufacturing paint use account for 17% of the total solvents sector, followed by domestic solvents use, decorative paints use, glue use, and offset printing account for 50% of emissions. This result shows that it is 16% lower than ECLIPSE, 3% higher than the VOC emission estimated by the Japan Environment Agency.

As a result, the distribution of solvent sector among VOC emissions showed the highest contribution and paint use sub-sector in solvents sector showed the highest contribution. The estimated VOC emissions showed less than 10% differences compared with other previous studies.

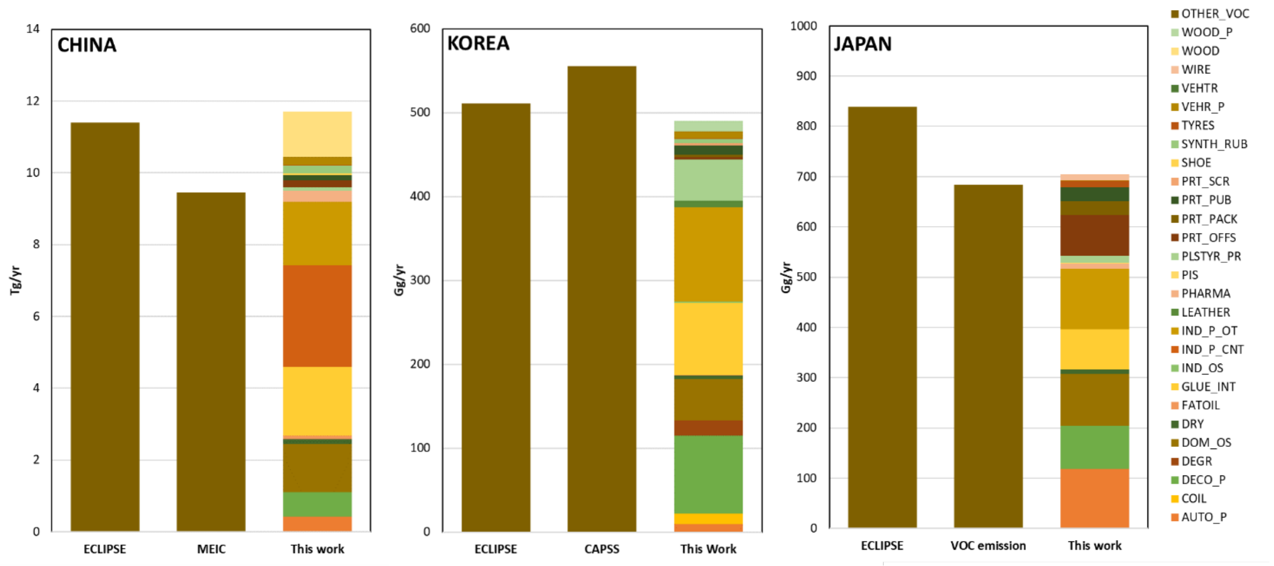


Figure 2 Comparison of VOC Emission in Solvents sector by Country

3.2 Chemical speciation of VOCs

Chemical speciation profile was improvement. VOC sector can be divided into Solvents, Transport, Industrial Process, and Fuel Combustion, and the chemical speciation profile is different for each sub-sector and for each reference. So it is important to use a profile that represents a reasonable value. Based on literature review, KORUS-AQ's observations and expert reviews, we created a reasonable profile. VOCs sector can be classified into solvents, transport, industrial processes, and fuel combustion. In the case of the solvents, aromatics is higher than that of other sectors, and in the case of the transport, the ratio of Alkanes and Aromatic is different, depending on the using fuel and type of vehicle. In the case of Industrial Process, distribution of Alkanes is more than half. Industrial Combustion is similar to Process, but the species rate of Alkenes is about 10% higher. In Power Plant and Domestic combustion, Alkane accounts for more than half.

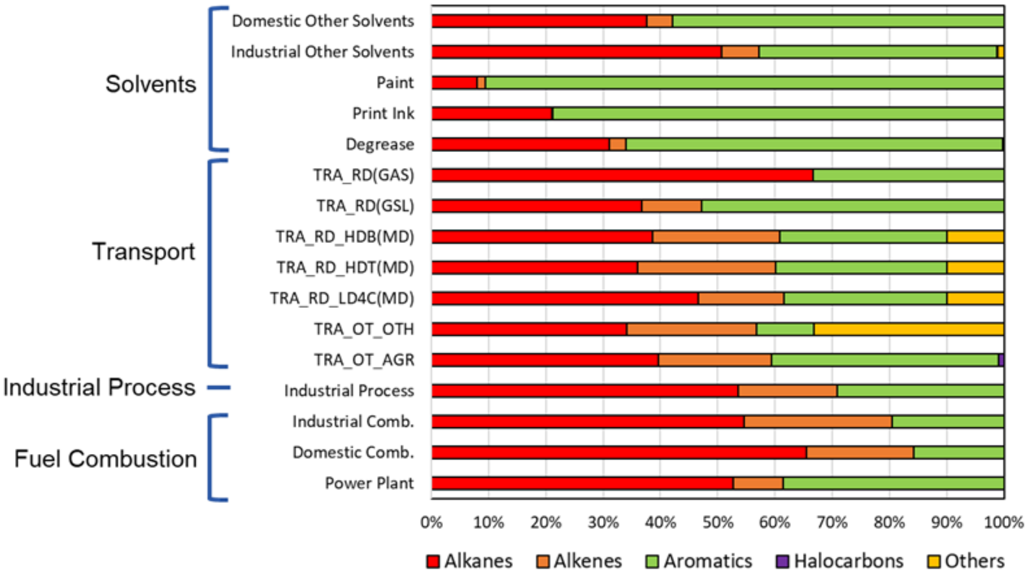


Figure 3 Chemical speciation profiles by sector

The emission distribution by chemical speciated VOC emission for each country is as follows. Mostly composed of Aromatics and Alkanes. The ratio of Aromatics is similar to that of the Solvents sector to the total VOC emissions in each country, with China accounting for 50%, Korea 53%, and Japan 60%. Aromatics is mostly caused by paint use.

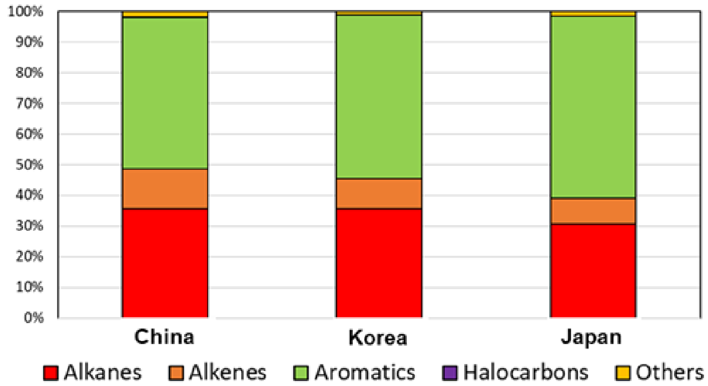


Figure 4 Chemical speciated VOCs distribution by Country

In all three countries, aromatics are mostly caused by paint use, and excluding solvents, alkanes represent the highest emissions from the industrial process sector. China has a large amount of VOC emissions in the industrial combustion sector, especially alkanes. Also, Domestic Combustion sector, unlike Korea and Japan, where VOC emissions are almost non-existent, but China seems to a considerable amount of VOC emission, also alkanes are generated, which seems to be from cooking stoves(Wang et al., 2018).

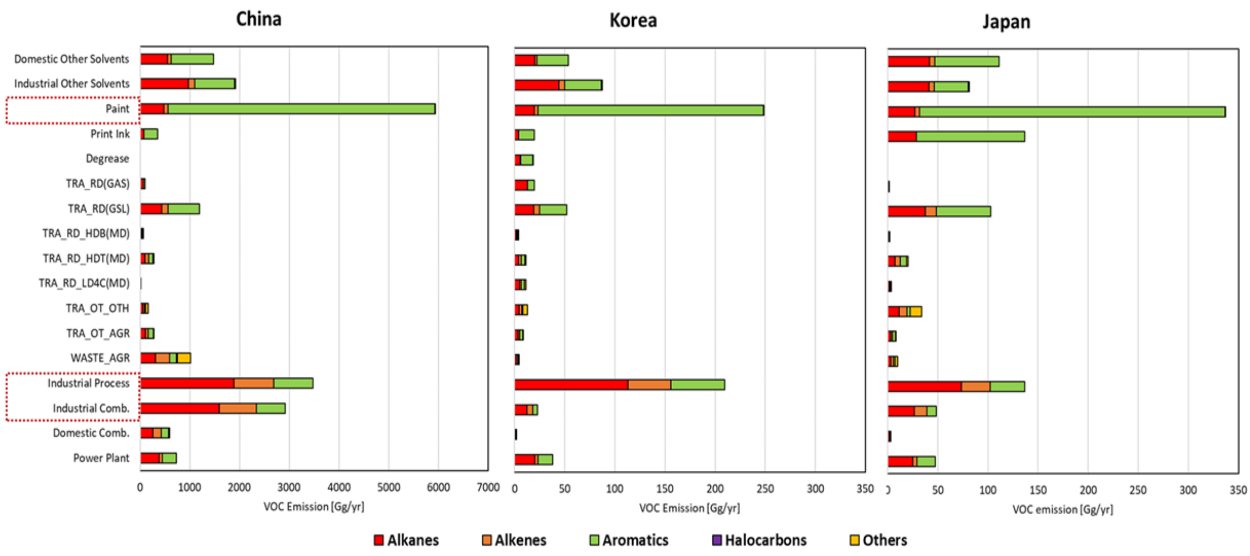
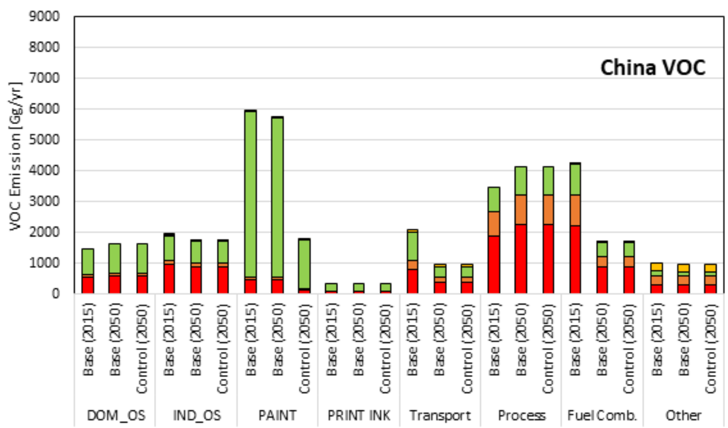


Figure 5 Speciated VOCs emissions by sector, country

3.3 Future VOCs and SOAs emission

Two future emission scenarios were created with the emission data that have improved with detailed sector and speciation information. For the base scenario, we followed the pathway from ECLIPSE_v6c_CLE_Base. The reduction technology in the paint use sector was implemented for the control scenario. There are 2 major reduction technologies in the paint use sector. Those are replacements for oiled paint to powder and water-based paint. We applied water-based paint in the Control scenario. As a result, VOC emissions in 2050 of the Control scenario were reduced by 36%, 49%, and 40% in China, Korea, and Japan respectively compared with the emission of the base scenario's VOC emissions in 2015. VOC emissions in 2050 were estimated to be 13.18 Tg/yr in China, 0.42 Tg/yr in Korea, and 0.65 Tg/yr in Japan.



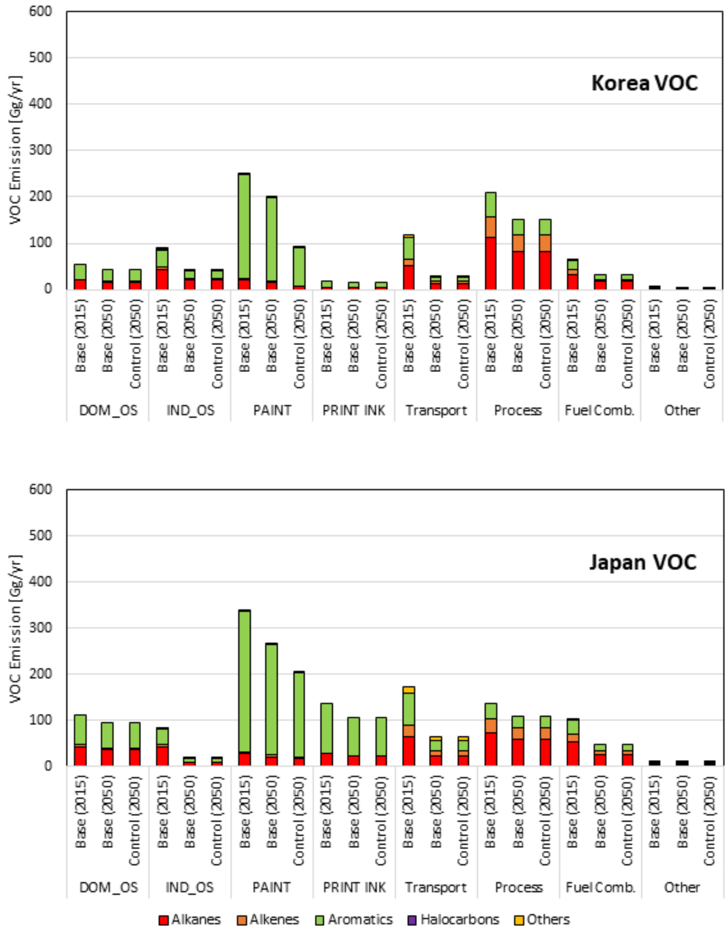


Figure 6 Chemical speciated VOCs emissions by sector, scenario, country

The SOA emissions was estimated by the FAC method (Grosjean, 1992). The FAC method is one of the methods that can estimate the SOA formation potential using chemical speciated VOC emissions without atmospheric chemistry modeling.

$$[SOA] = [VOC] \times FAC \times faction\ of\ VOC\ reated$$

[SOA] : Amount of aerosol produced (Gg/yr)
[VOC] : Amount of VOC emitted (Gg/yr)

SOA emissions were estimated with the Base scenario and the Control scenario. As a result, SOA emission showed the higher emission than VOC emission in 2015. The paint use sector is the most contributor on both VOC and SOA emission. That's because the huge aromatic emissions are emitted on the paint use sector and the aromatic has high value for SOA yield. SOA emissions in 2050 by Control scenario were estimated in 11.84 Tg/yr for China, 0.43 Tg/yr for Korea, and 0.74 Tg/yr for Japan. These results showed 43%, 51%, and 39% of emissions reduction in China, Korea, and Japan respectively compared to the SOA emissions in 2015.

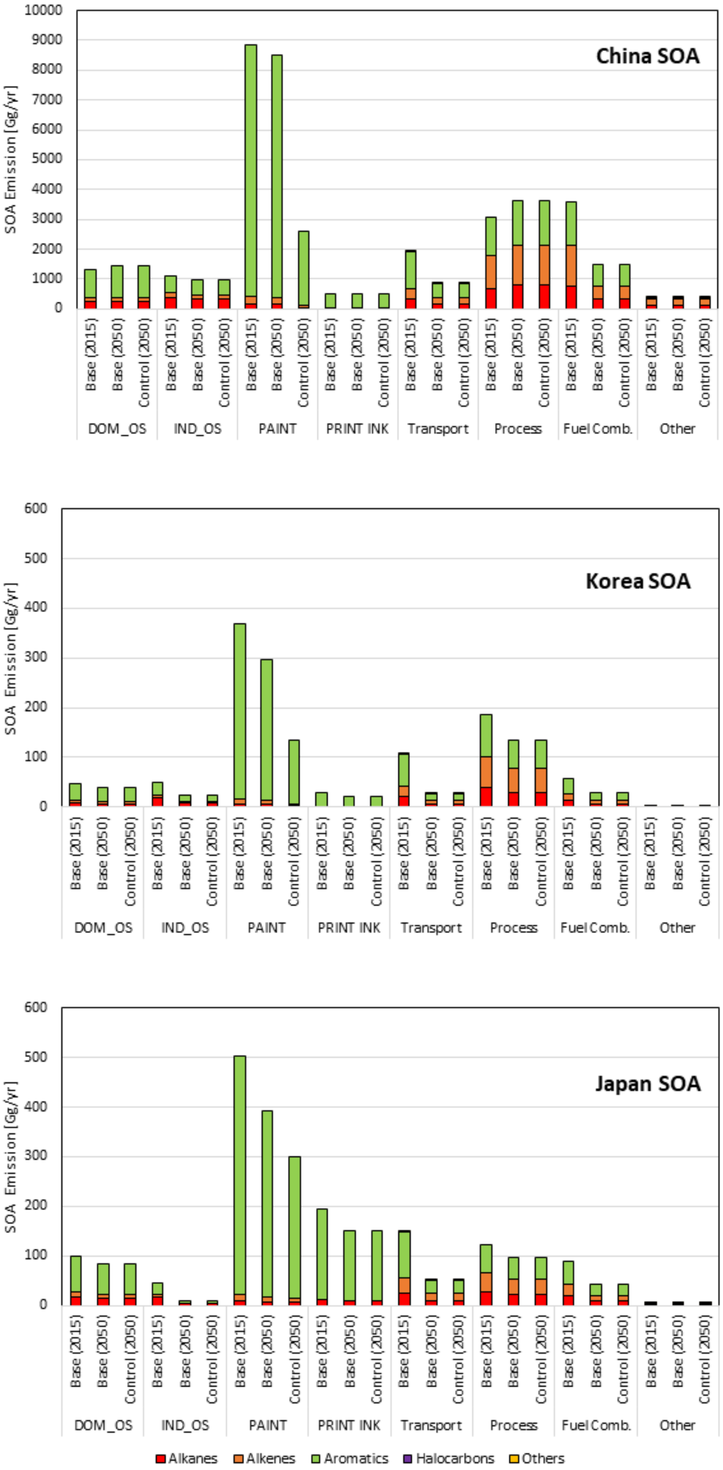


Figure 7 Chemical speciated SOAs emissions by sector, scenario, country

3.4 Biogenic VOCs and SOAs emission

Biogenic VOC emissions was estimated using the MEGAN model. In the case of BVOCs, seasonal emission patterns are important, and may result in higher emissions than AVOCs depending on the season. In this study, the annual emissions were estimated because seasonal changes were not important. BVOC and SOA emissions were estimated in 2015, the same base year as AVOC. Most of biogenic SOA(BSOA) emissions were estimated to be at the ratio of 10% of BVOC emissions. On the other hand, ASOA emissions was estimated to be similar to amount of AVOC emissions or 10% higher than AVOC emissions.

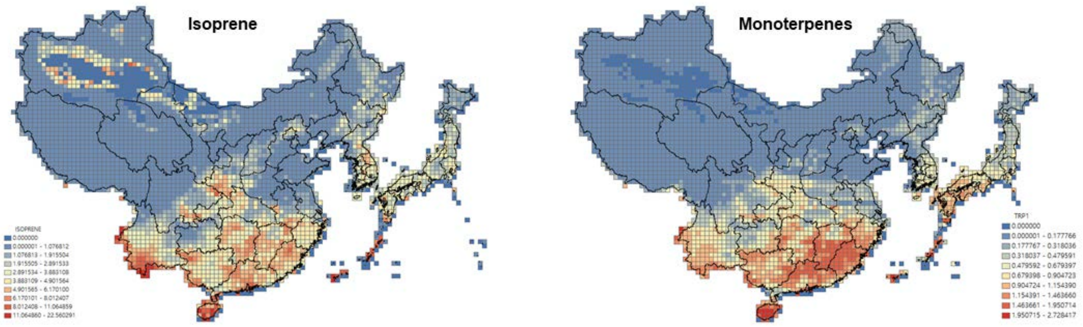


Figure 8 Distribution of BVOC Emission in 2015

Table 1 BVOC and BSOA Emission in 2015

[Gg/yr]	Isoprene	Monoterpenes	BVOC	BSOA
China	11,121.5	3,882.2	15,003.7	1,550.1
Korea	383.7	160.3	544.0	61.4
Japan	750.2	314.7	1,064.8	120.4
Total	12,255.3	4,357.2	16,612.5	1,731.9

3.5 Primary vs. SOA emissions control

SOA emissions in Base scenario and Control scenario has compared with primary PM(PM2.5) emissions. PM2.5 emissions in the base year were 8.66 Tg/yr in China, 0.11 Tg/yr in Korea, and 0.13 Tg/yr in Japan. SOA emissions are 22.20 Tg/yr in China, 0.93 Tg/yr in Korea, and 1.33 Tg/yr in Japan, which is 2.6 times higher in China, 8.4 times in Korea, and 10.5 times in Japan than PM2.5 emissions. In addition, we considered whether PM reduction is possible through policy reduction of secondary PM (SOA). In the case of Primary PM (PM2.5), an emissions reduction of up to 10% was estimated in 2050 compared to 2015. In addition, an emissions reduction of up to 30% in 2050 compared to 2015 was estimated as a reduction policy for VOC-SOA precursors. In 2050, the control scenario showed an additional reduction effect of up to 20% compared to the base scenario. In Korea and Japan, the VOC reduction policy was more effective than the Primary PM reduction policy for PM reduction. These results indicate that three countries in northeast asia have large potential for improvement of fine particle pollution by NMVOC reduction.

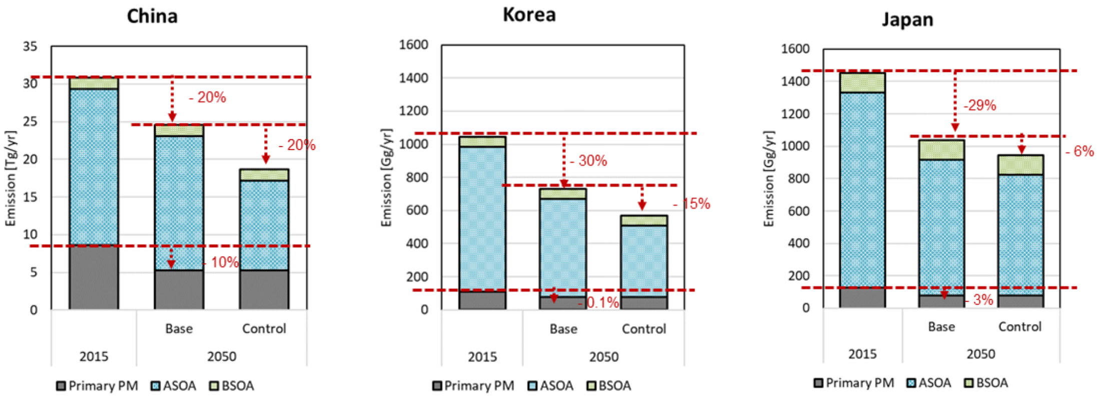


Figure 9 Comparison of primary PM and Secondary PM(SOA) by scenario, country

4. Conclusion

In this study, VOC emissions at the sub-sector level of three Northeast Asian countries were calculated using GAINS. The main VOC sources are the Solvents sector (i.e. Paint use, Printing Ink) and the Industrial Process sector. In China, the Industrial Combustion sector and Domestic Combustion sector also emitted, because the emission reduction device was the low efficiency.
VOC emissions and SOA production from chemical species were estimated. Aromatics was mainly emitted from the solvents sector, and alkanes and alkenes were mainly emitted from the industrial process sector. In China, the emission distribution of Alkanes and Alkenes was higher than that of Korea and Japan. The Solvents sector has the largest SOA emissions, because VOC emissions were the largest and thethey have a high SOA yield of Aromatics. The three countries produced up to 111% of ASOA emissions compared to AVOC emissions, but BSOA production only accounted for 10% of BVOC emissions. The three countries produced more SOA than primary PM, and emitted up to 10.5 times in Japan.
By comparing the emissions of the Base scenario and the Control scenario, the PM reduction effect through VOC reduction was studied. In the paint sector with the largest VOC emission, a policy of switching from oil-based paint to water-based paint was applied. As a result, compared to the Base scenario, SOA emissions were reduced by up to 20% in the Control scenario. In China, PM2.5 emissions were reduced by 10% in 2050 compared to 2015 through the primary PM reduction policy, and SOA emissions were reduced by 20% through the VOC reduction policy. By applying Control, SOA emissions were further reduced by 20%. However, in Korea and Japan, the reduction of primary PM in 2050 compared to 2015 was less than 3%, and the SOA emission reduction effect was reduced by 30%. From the scenario study, China shows high control potential in both primary PM and SOAs. Only SOAs emission, however, show great control potential in Korea and Japan, where primary PM emissions are already been reduced much.